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ULTRA-WIDE-FIELD TIME-LAPSE PHOTOGRAPHY FROM AIRCRAFT

By

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ULTRA-WIDE-FIELD TIME-LAPSE PHOTOGRAPHY FROM AIRCRAFT

Introduction

Recent experiments have shown that time-lapse methods are useful in photographing the earth, the sea surface, and cloud forms from aircraft in flight. For these purposes the camera is trained ahead so that equal attention is given to earth and sky and the component of relative motion is at a minimum. A wide field of view is required since conditions often are such that large objects are screened from sight at more than moderate ranges, and it is not always known in advance what objects may prove to be of interest or where they may lie with respect to the flight path. It is also helpful to be able to study an unfamiliar object or pattern from a variety of points of view so that fields as large as 150° total angle seem desirable for oceanographic and meteorological surveys. Ordinary motion picture cameras cannot accommodate them.

Time lapse film as a flight log

At a time lapse of 1 second between frames the events of an hour of flight are recorded on approximately 100 feet of 16 mm film which serves as a detailed and objective flight log. The changes in successive images are small enough to give the illusion of hurried but acceptably smooth progress at ordinary projection rates if the flight was made above 500 feet at speeds in the order of 100 knots.

The record may read in a number of ways. The film can be reviewed qualitatively in 1/16th the original flight time, when projected at 16 frames per second, and stopped or reversed as necessary. When stretched out along the direction of flight, the film represents a dead reckoning plot of the flight and indicates the relative positions of successive objects or events. The scale of the dead reckoning plot is compressed by the ratio of the length of film advanced between exposures to the distance traveled by the airplane in the same interval of time. For the one-second time lapse the ratio falls in the range from 1/5000 for slow aircraft to as much as 1/30,000 for the fastest. The angular dimensions of distant objects can be reduced to approximate linear dimensions from a knowledge of the airspeed and time required to close with them after sighting. More exact linear measurements are possible if the perspective geometry of the changing point of view and distortions of the optical system are taken into account.

Some methods for obtaining ultra-wide-field photographs

The problem of horizontal wide-field photography from the air is unique in many ways. The range of horizontal vision from aircraft is limited only by atmospheric haze or the true horizon. Hence the object space is radially symmetrical and can be assumed to be either spherical, cylindrical or toroidal rather than plane. Each assumption has a number of possible consequences in photographic procedure.

A procedure for photographic reproduction of cylindrical object spaces on a flat surface is already implemented by the old-fashioned panoramic camera. In a familiar case, such as the members of a convention standing in a semi-circle around the camera, one obtains a cylindrical projection (similar to Mercator's) of the group on a flat film which is curved during exposure. This method is practicable in terms of motion picture mechanisms for aircraft but the time required for the lens and slit to cover the focal surface would allow the image to be distorted in proportion to the change of the point of view during each exposure. A similar solution of the toroidal problem would yield a different cylindrical projection but would suffer from the same defect, which is enough to lead one to seek other alternatives.

It is quite possible, for example, to utilize the tri-metrogon principle in motion picture photography as has already been done in the Cinerama technique. This requires three cameras and films, and later on three projectors, all fairly well synchronized and aligned. This amount of complexity and expense is uninviting.

It is also conceivable that one camera might be trained on successive azimuths either directly or by means of a rotating mirror, so that every third frame, for instance, might represent a sequence of views in one direction. Were a similar rotating mirror system to be placed before the projector the reversion of the camera mirror would be cancelled and very wide fields of view be generated presumably on folded flat screens. Except for the mirror or training mechanisms these principles could be applied with standard cameras and projection equipment. These are essentially photo-mosaic techniques.

There are still other possible systems which utilize flat film but permit the final image to exhibit marked amounts of barrel distortion. Since this distortion can be removed during projection, these systems have been given some study. They are not recommended as the best solutions but they are simple to construct and seem useful for certain kinds of scientific work.

Orthographic imagery

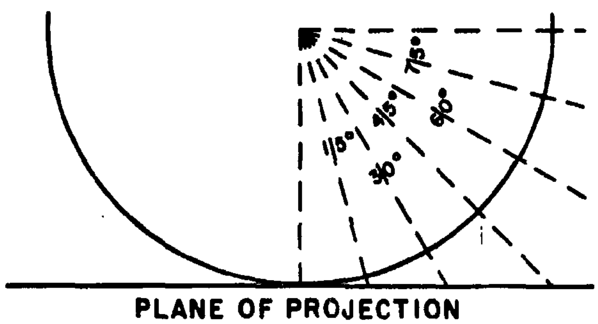
In order for the perspective of a field of view to be correct in a projected or printed image it is necessary that the angles originally subtended at the camera lens be reconstructed from the point of view of the observers eye. This condition can be satisfied comfortably for flat fields in the order of 40° total angle and remains possible for fields even as great as 100°. As the angle of view increases still more, however, the eye point approaches the image plane too closely and will eventually coincide with it.

Ordinarily, camera lenses are designed to follow the rules of gnomonic projection (Fig. 1) which are perfectly satisfactory for most purposes. The pinhole camera produces this type of projection, which is the same as a fixed view through a window referred to the pane of glass. In either case, the image scale must increase toward the edges of the field of view. This increase in scale becomes more and more difficult to provide when the field of view exceeds one radian.

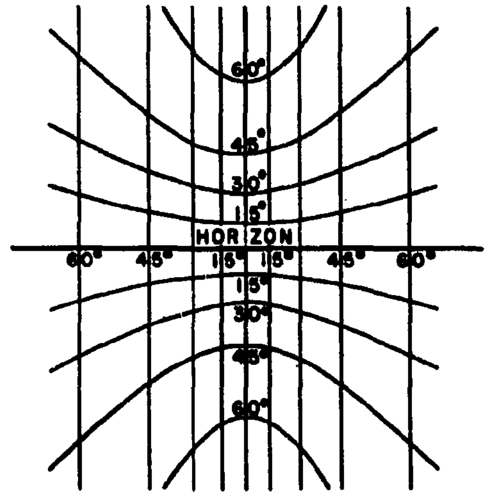
It may even be undesirable as in connection with horizontal photography from aircraft, since the vertical dimensions of the image then depend on the position of the object in the picture. If the point of view is not taken exactly at the center of perspective, fixed objects appear to change size as they cross the field during turns. In the orthographic projection (Fig. 2) the vertical dimensions of given objects remain the same regardless of their azimuth. Their horizontal dimensions change, but

GNOMONIC PROJECTION

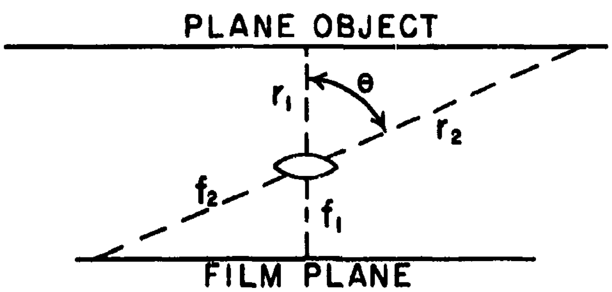
PRINCIPLE OF PROJECTION



GNOMONIC NET

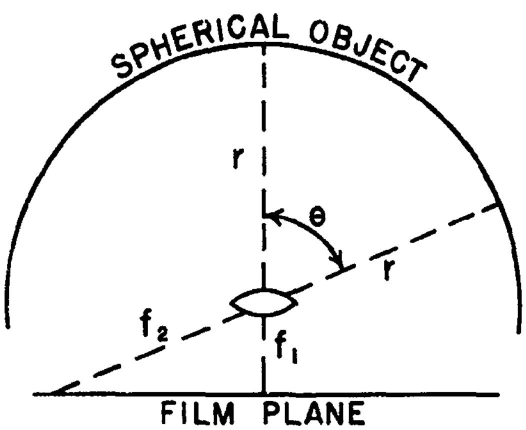


GNOMONIC PROJECTION OF THE HORIZON SYSTEM OF COORDINATES. VERTICAL CIRCLES ARE STRAIGHT AND PARALLEL. CIRCLES OF EQUAL ALTITUDE ARE HYPERBOLIC.



$$\frac{r}{f} = \text{CONST.}$$

$$r, f \sim \text{SEC } \theta$$



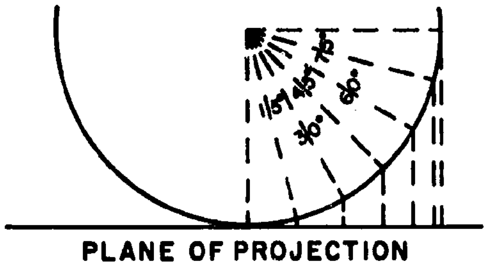
$$r = \text{CONST.}$$

$$f \sim \text{SEC } \theta$$

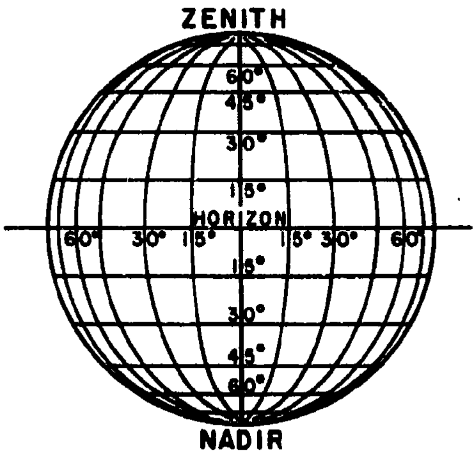
FIG. 1

ORTHOGRAPHIC PROJECTION

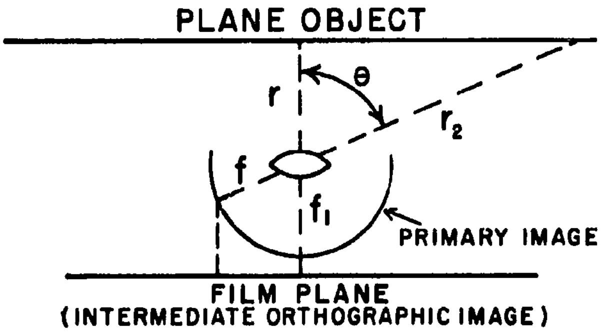
PRINCIPLE OF PROJECTION



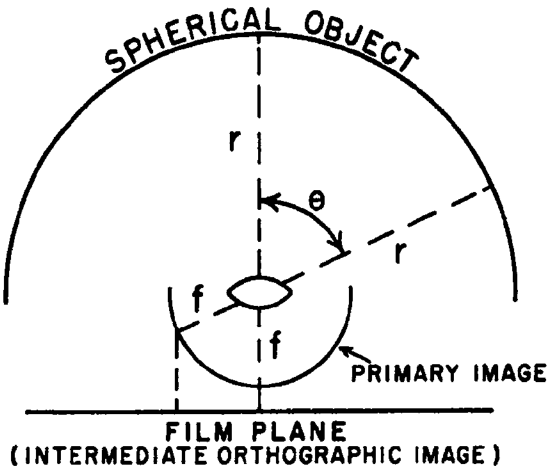
ORTHOGRAPHIC NET



ORTHOGRAPHIC PROJECTION OF THE HORIZON SYSTEM OF COORDINATES. VERTICAL CIRCLES ARE ELLIPTICAL. CIRCLES OF EQUAL ALTITUDE ARE STRAIGHT AND PARALLEL.



$$\left.\begin{array}{l} f = \text{CONST.} \\ r \sim \text{SEC}\ \theta \end{array}\right\}$$ IN PRIMARY IMAGE AND FINAL IMAGE WHEN FORMED ON A SPHERICAL SCREEN



$$\left.\begin{array}{l} \frac{r}{f} = \text{CONST.} \\ r, f \sim \text{SEC}\ \theta \end{array}\right\}$$ IN PRIMARY IMAGE AND FINAL IMAGE WHEN FORMED ON A SPHERICAL SCREEN

FIG. 2

since this change is the same as everyone has observed when idly spinning a terrestrial globe, the effect is familiar and not at all disturbing. These effects disappear entirely in either projection when the eye is at the center of perspective, but then one cannot see the whole field of view at once.

Since it is desirable both to be able to restore the original angular dimensions of the object space and also to study the whole image in a rationally distorted framework, the orthographic projection offers unique advantages. Optically, it is simpler as well, for the scale of the image usually tends to diminish radially outward from the center of the field, producing negative or barrel distortion unless compensating lenses are added which tend in their turn to reduce the angle of the field.

When barrel distortion is permitted to increase it is entirely possible for the field width to open to and beyond a full hemisphere. If the radial scale is an harmonic function of the angle of view and of the first order, the image takes on the properties of the orthographic projection of a sphere. Through suitable control of distortion with respect to this projection, the image can be restored to spherical shape when it is projected on the interior or exterior of a spherical shell. The center of perspective then coincides with the center of curvature of the spherical shell, and from this point, or on looking through this point, the angular dimensions of the image appear to be normal.

When necessary, angles can be measured directly from or through the center of perspective of the spherical image with the same facility as with conventional photoalidades and flat prints. However, the spherical method makes it no less difficult to maintain high image quality over a very wide field of view. Spherical projection systems are perhaps most suitable for preliminary studies of objects or patterns that subtend large angles at the longest practicable ranges.

Orthographic systems

A number of different optical systems will produce an orthographic projection of a spherical object space on a flat film (Fig. 3). In all cases the field angle is first compressed to a spherical miniature of the world outside and then this image is focused on the film plane. These may be classed as positive systems in which at least two real images are formed in succession; or negative systems in which the first image is virtual and only the second is real. The positive systems employ either positive lenses or concave reflectors as field compressors while the negative systems utilize either negative lenses or convex reflectors for that purpose.

Field compressors of the reflecting type offer some optical advantages, being achromatic and single surfaced but to provide an orthographic image the curves must be aspheric. (Spherical reflectors offer a group of possibilities all their own which are of great interest). The systems also require either secondary reflecting elements or that the camera mechanism be placed in the field of view. When reflecting systems are mounted in an aircraft either the secondary reflector or the camera must be mounted outboard in the airstream and be

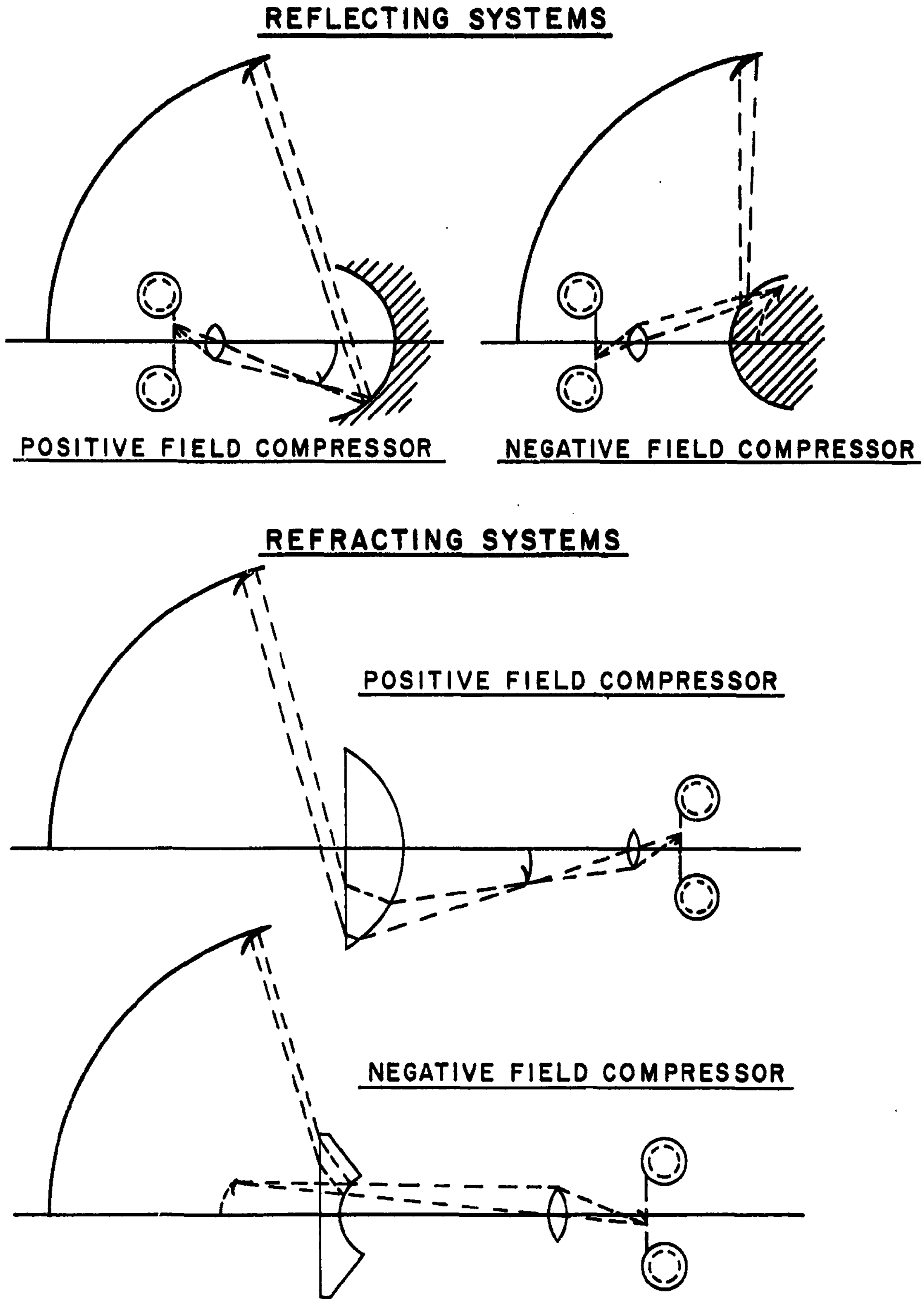

REFLECTING SYSTEMS
POSITIVE FIELD COMPRESSOR
NEGATIVE FIELD COMPRESSOR
REFRACTING SYSTEMS
POSITIVE FIELD COMPRESSOR
NEGATIVE FIELD COMPRESSOR

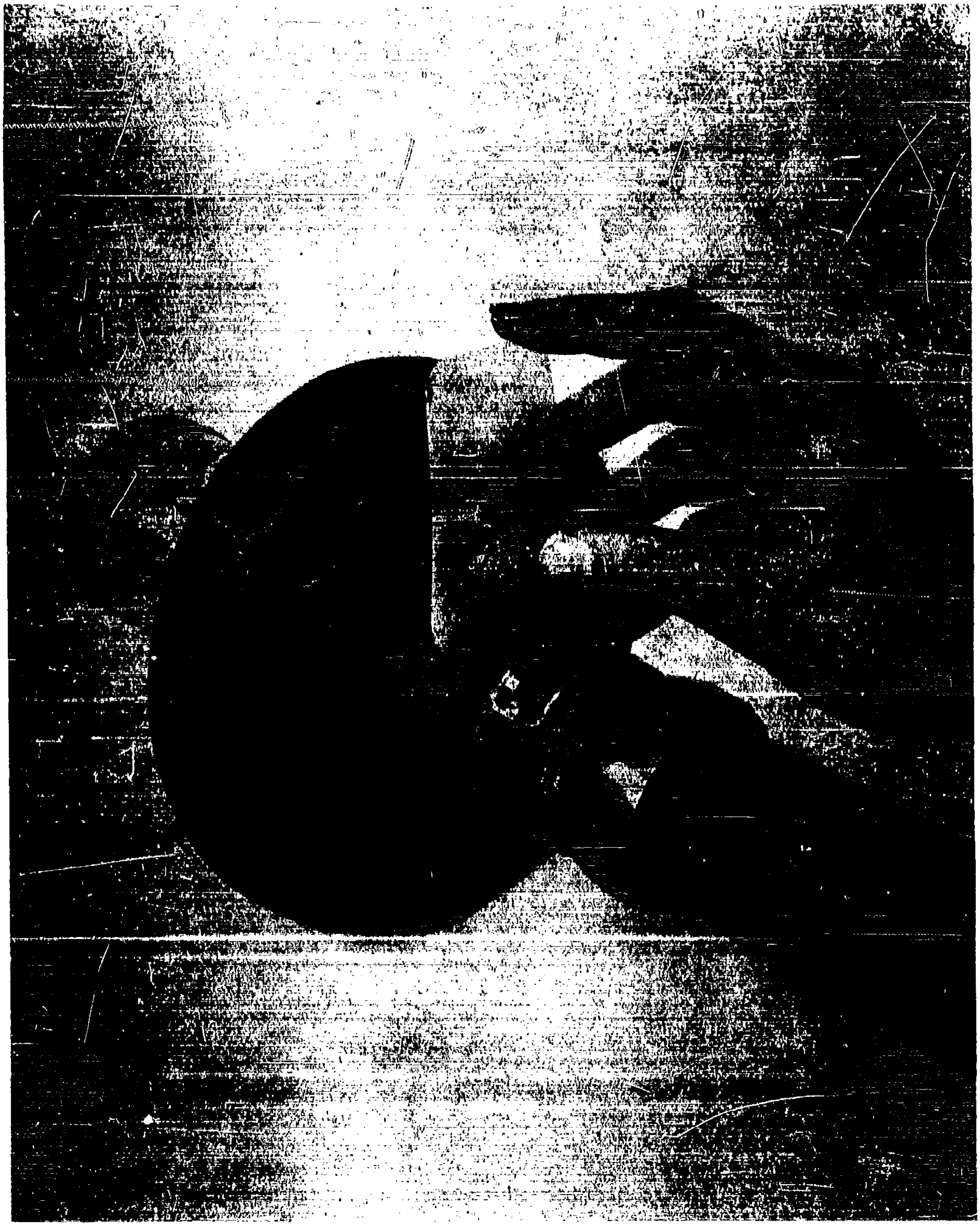
FIG. 3

subjected to the buffeting of wind and occasional wetting in squalls. Were the camera outboard it would have to be recovered to change films. These design requirements could be met if necessary but they have been avoided by the use of refracting systems which are inherently orthographic and can be arranged to have all but the field compressor mounted inboard.

The plane of the first real image of a refracting field compressor of the positive kind can also be inboard. This makes it possible to insert reticles or notes written on translucent plastic slips concerning course, speed, altitude, time and other matters to be recorded directly on the film while in flight (Fig. 4). The slips are illuminated by the first image so that the exposure is adequate and the note is properly and permanently placed in the time sequence of the flight log.

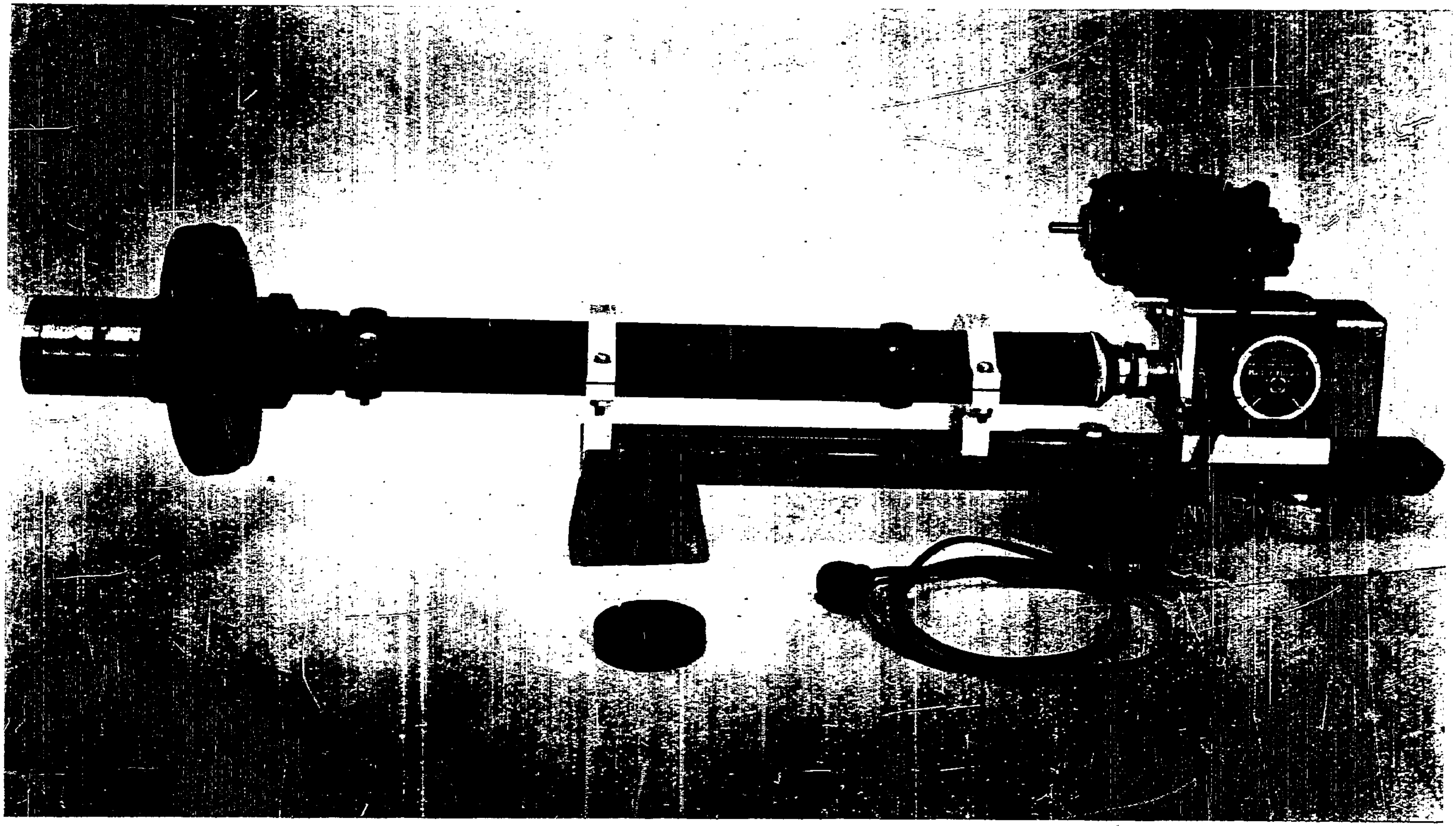
An experimental orthographic system

The optical system that has been used experimentally at WHOI in a PBY-6A consists of a high quality 5x gunsight telescope (M71) placed wrong-end-to before a 16 mm magazine-load Bell and Howell camera fitted usually with a 44 mm f.l f/3.2 objective (Fig. 5). The eyepiece of the telescope either alone or with auxiliary lenses is in effect a positive field compressor which reduces the true field of view of 65°, 80°, or 145°, to about 12°. The erecting system performs its designed function and permits the camera to be run in an upright position. The objective of the telescope acts as a collimator so that the image produced by the field compressor appears to be at infinity. The camera lens, therefore, produces a sharp final image when it is



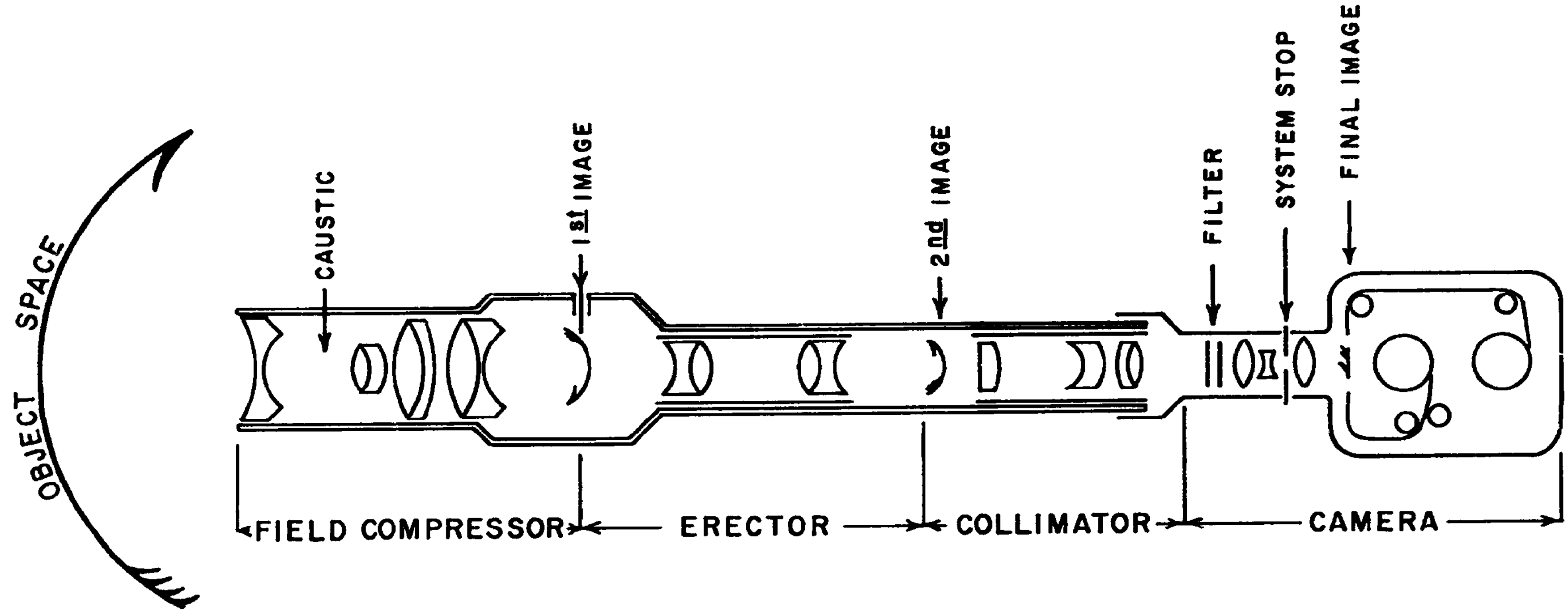
Slot at focal plane of the field compressor for insertion of notes in flight.

FIG.4



Side view of bow camera assembly

FIG.5



OPTICAL TRAIN OF THE PBY BOW CAMERA
(SCHEMATIC)

FIG.5A

focused for infinity. As there is no limiting aperture in the optical train ahead of the iris diaphragm in the camera lens, this acts as the system stop. Thus the lens manufacturer's stop markings remain correctly calibrated. There are light losses due to added absorption and reflections in the optical train, but these are constant and can be compensated by either determining the "filter factor" of the system or by making equivalent corrections of the effective film speed.

The 65° field provided by the unmodified telescope eyepiece is fairly free of barrel distortion, but is a little small for aerial survey work over the ocean. This field has been increased by means of auxiliary lenses. These introduce barrel distortion in amounts which can be directly related to a spherical screen with ordinary 2-inch projection lenses. When the projector is more than ten radii away from the spherical screen the image is sufficiently close to an orthographic projection to fulfill ordinary requirements. The auxiliary lenses were adjusted as follows:

If R is the radius of the field extended to include objects of 90° off axis, the radial scale of the final orthographic image should decrease as $R \cos \theta$. If this convention is satisfied, lines of equal altitude (almucantars) remain straight and parallel to each other across the full width of the field. The spacing of almucantars also decreases as $R \cos \theta$ toward the upper and lower limits of the field. It is most convenient to test the whole system at once by inspecting the final image. The field compressor and auxiliaries are first adjusted to render the almucantars parallel in the final image. Further adjustments may be required in focusing the collimator and camera to produce the proper change of image scale horizontally and vertically.

The eyepiece itself is of the class of positive field compressors. It is characteristic of this class that all the oblique rays within the limits of the field cross the axis a short distance ahead of the first glass surface to form a caustic, which was the eye point of the original telescope system. The angle at which the extreme rays may enter this caustic can be increased by increasing the total power of the field compressor system. This may be accomplished by adding a positive lens at the original field lens or more conveniently by means of a positive lens inside the caustic or a negative lens beyond it. In the latter cases adjustment of the barrel distortion can be made not only through a choice of radii but also through changes in the position of the auxiliary lens with respect to the caustic. It is found that plano-convex positive elements and plano-concave negative elements mounted with their plane surfaces facing the object space are most suitable. A field of very nearly 180° can be obtained with either negative or positive elements. This angle can be exceeded with negative meniscus auxiliaries. Because of the increasingly rapid reduction of the image scale radially, it seems unprofitable to press the angle of view very much beyond 160° on the 16 mm film format.

Curvature of field is almost certain to be present in the primary image of the field compressor, whether the system be positive or negative, reflecting or refracting. This can be removed at either the initial or the final image plane, but if the curvature is small enough to be accommodated within the limits of the depth of field of the camera objective, it can be neglected. A camera objective of short focal length has a deep field and at the same time may work at high relative aperture in proportion to the diameter of the entrance pupil. The latter is of consequence since the diameter of the largest bundle of rays entering the system stop must be kept small (well under one centimeter) so that the astigmatism associated with the caustic may not become too pronounced.

These optical difficulties prevent existing systems from covering the whole width of field with uniformly high image quality at all useful relative apertures. At f/1.9 acceptably stigmatic images can be recorded over only the central radian of field. Ordinarily, in the air the required stops may be in the range f/8 to f/11, hence the image quality is improved and becomes fairly uniform to the edge of much wider fields. Although the image quality is never up to the best standards, neither should it be classed with the worst. Illumination over the full field width is remarkably uniform.

Owing to the position of the system stop the $\cos^4\theta$ law of decreasing illumination does not hold for the total field in these systems but only for the limited angle of view accepted by the camera lens. Thus it is possible to utilize color films having a latitude of only about 2 stops. An effect related to the $\cos^4\theta$ law does apply to the true field later on, however, because of the obliquity of the projected light on the rim zones of the spherical screen. Since the eye can tolerate a very much wider range of brightnesses than any emulsion, this deferment of an inevitable effect is desirable.

While illumination is uniform enough within the optical system, there is often a wide range of brightness from one part of the field to another. The direct rays of the sun may be included at times so that the system must be designed to minimize internal reflection or flare.

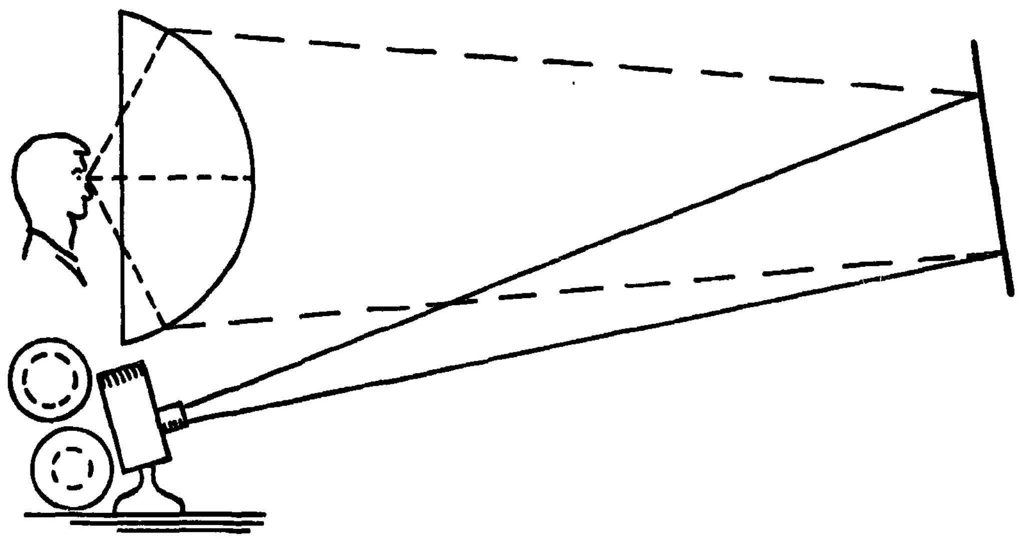
Exposures must be measured over the whole field of view. This may be done by scanning the field with a narrow angle meter, such as the G.E. Type DW-68, a special wide-angle meter, or by incident light readings with adjustment for the albedo of the subject. It seems best to underexpose color films made from the air. Therefore, if the range of brightness (other than directly into the sun) is as great as 3 stops, it is best to place the 2 stop range of the film at the high end of the brightness range. This means that the exposure is correct only for the upper two stops of the brightness range, and that the color is oversaturated in the darker portions of the photograph. This turns out to be preferable to either centering the exposure or favoring the less bright portions of the field since nothing is washed out by overexposure. Half-field neutral filters might be useful.

The contrast of these wide angle films often seems to be unusually high especially when studied on a flat screen or from a point well behind the center of perspective. This is mainly illusory and arises from the compression of the familiar gradients of color or brightness. Still a useful purpose is served in calling attention to gradients that are weaker than those readily perceived by the unaided eye. Stratiform clouds, for example, often seem featureless to the eye, but exhibit surprising amounts of detailed structure on wide angle films. It is found that slicks on the sea surface seem more numerous in these photographs than to the eye because many of them are quite broad and involve subtile differences in the reflected color or intensity of light originating in closely adjacent portions of the sky.

It is found that some contrast is lost when the image is formed on an opaque concave spherical screen because of light scattered across the bowl. The concave screen does possess an accessible center of perspective but the observer's head will obscure part of the image if he occupies it. The center of perspective of the opaque convex spherical screen is inaccessible. Figure 6 shows an arrangement utilizing a translucent spherical screen and one plane reflector to revert the image. The screen also reflects some light so that the image is visible to more than the observer at the center of perspective.

Installation

The mechanical arrangements for installation and operation of the bow camera in the PBY were simplified by the existence of a hawse hole in the bow. The hawse hole cover has been replaced by a sponge rubber cover which contains a hole large enough to hold the field compressor of the camera. This cushion acts as the forward shock mount and wind screen. The camera is run out

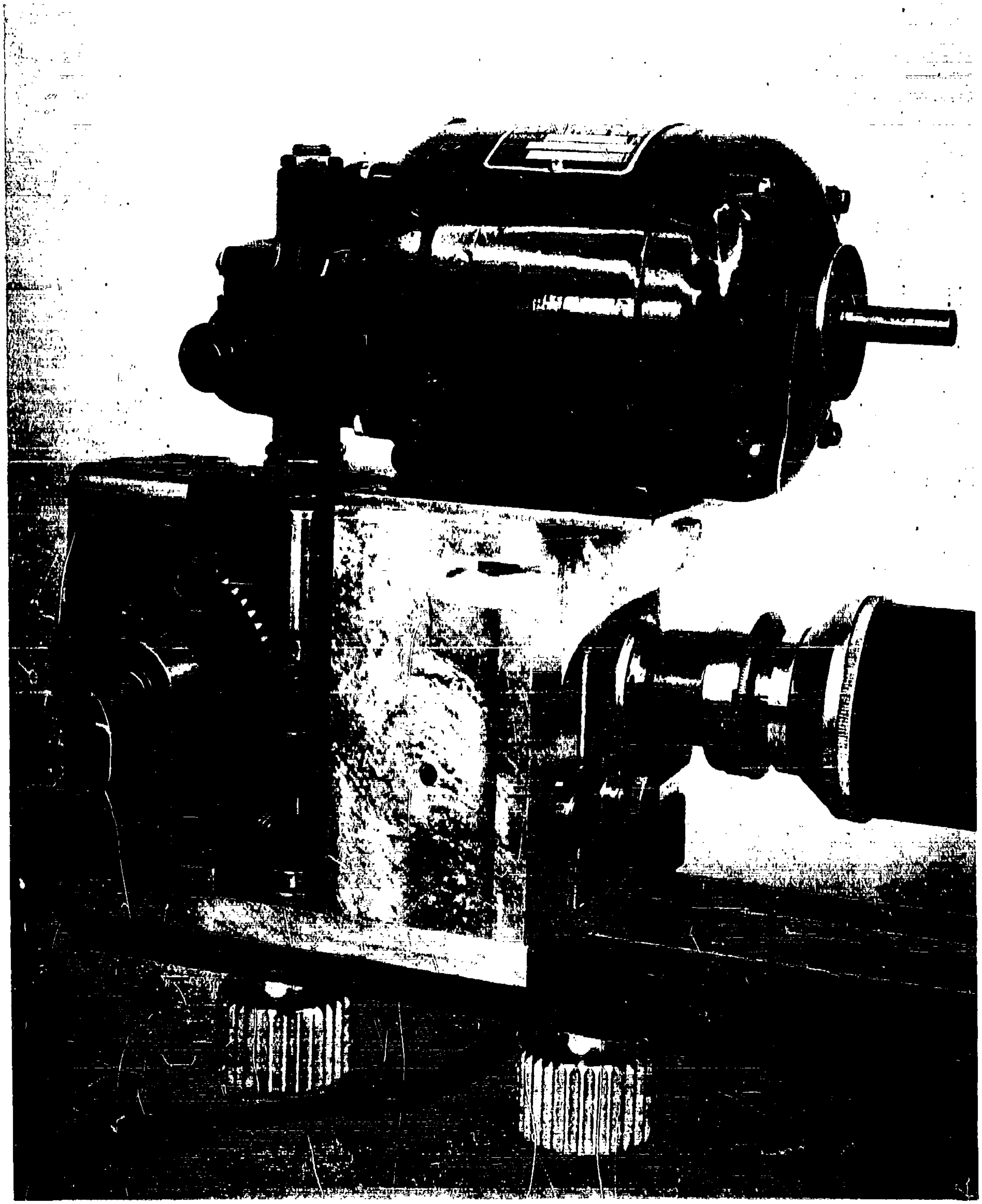


METHOD OF PROJECTION WHICH PERMITS EYE TO OCCUPY THE CENTER OF PERSPECTIVE AND TO HAVE PROJECTOR NEAR AT HAND. REFLECTION FROM THE PLANE MIRROR COMPENSATES REVERSAL OF LEFT AND RIGHT OTHERWISE OCCASIONED BY A TRANSMISSION SCREEN.

FIG. 6

through the hole until the slit for written notes is just inside the skin of the airplane. The bow camera is about three feet long so that the camera, stop control, and magazine compartment are beside the bowman as he kneels on the pad before the bombardier's window. The inboard end of the camera is bolted through shock mounts to temporary framing. The shock mounts are designed to damp vibrations mainly in the range 1200 to 2000 cycles, and seem to be satisfactory. Actually, the image scale is so small and the field of view so wide that ordinary engine vibration or even landing shock has little effect on the image quality. Shock mounting is necessary mainly to keep bolts and the set screws of optical components from being shaken loose over a period of hours. Film magazines are also less likely to jam if they are not subjected to intense vibration.

Two kinds of time-lapse triggering mechanisms have been used. The first was simply a 6 volt Permag motor fitted with an eccentric which tripped the single frame button on the camera through a bell crank. The camera was wound by hand. This required attention every five minutes, but since the bow observer's other duties were to set the camera diaphragm, change film magazines every half hour, insert notes in the film log, and act as forward lookout, he had to stay forward anyway. But when other programs found use for the bow camera there were such demands on the time of the bowman that it seemed desirable to provide a motor drive (Fig. 7). This drive consists of a Bodine motor turning at 60 rpm which will trigger the single frame button once each revolution and at the same time turn the



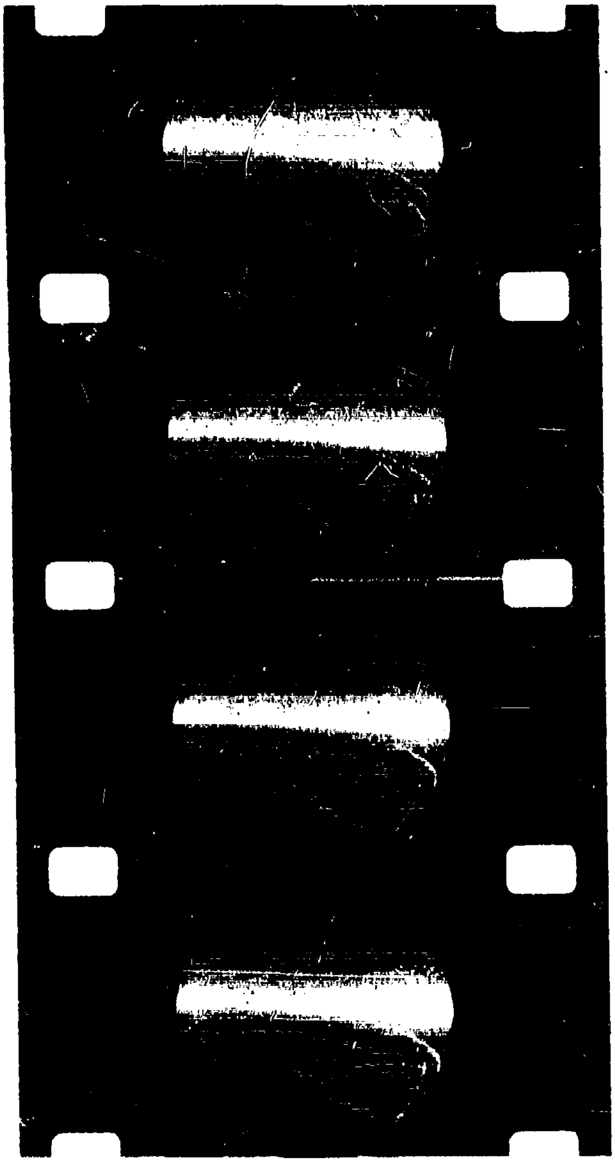
The motor drive

FIG.7

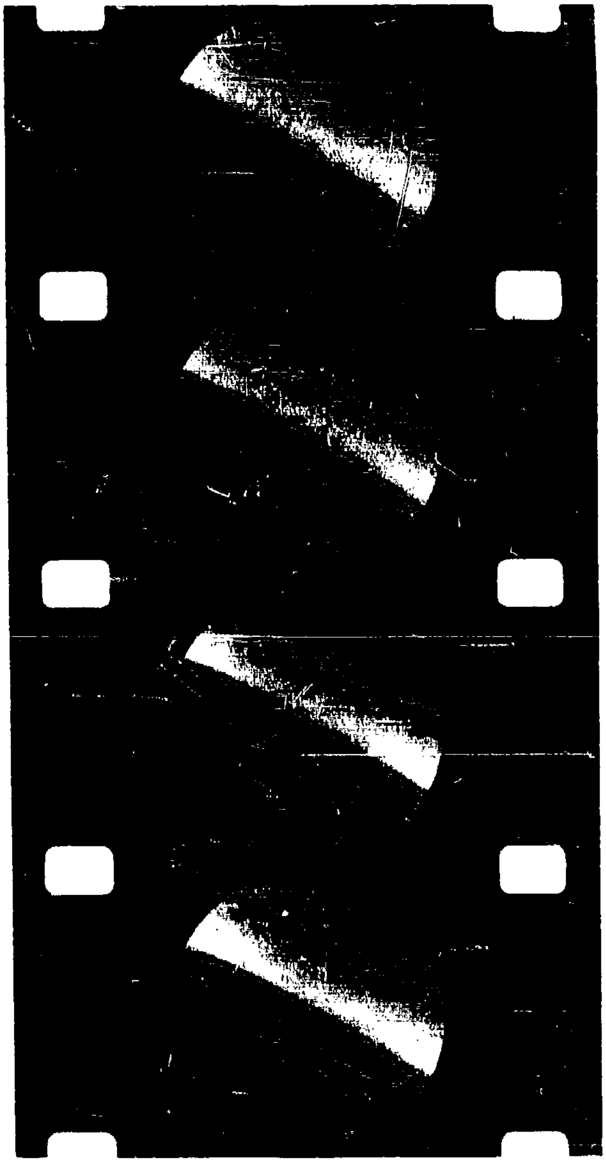
going barrel of the camera spring 1/60th of a revolution, which in this case restores the spring tension lost during each exposure. The camera spring requires three inch-pounds of torque to be wound, hence the motor drive is a fairly powerful affair. There is stop-work on the going barrel of the camera spring which will stall the drive if the film should jam, but there remains a certain risk of damage to the camera which is not present in the lighter, hand-wound arrangement. It would be desirable to arrange to break the circuit to the motor or include a shear pin in the linkage.

Other possibilities and applications

While these experiments with ultra-wide field time-lapse systems were undertaken merely to find means to develop an instrument for a specific purpose, they may have application to other problems such as the motion of clouds or in underwater photography where again, haze makes it difficult to place the camera very far from the bottom and inequalities of illumination are troublesome. While not designed to utilize the 16 mm film format, there are a number of commercial and experimental lenses and reflecting systems which may be adapted to it if a suitable field lens is placed in the focal plane. The Zeiss Pleon, the Robin Hill Sky Lens, made by Beck of London, and the Zeiss Versuch Nr. 18 (1936) cover fields of 136°, nearly 180° and 210°, respectively. These employ negative field compressors and are classed as reversed telephoto systems. Recently, Wollensack in the United States and Angenieux in Paris have begun to market reversed telephoto lenses for 16 mm amateur motion picture

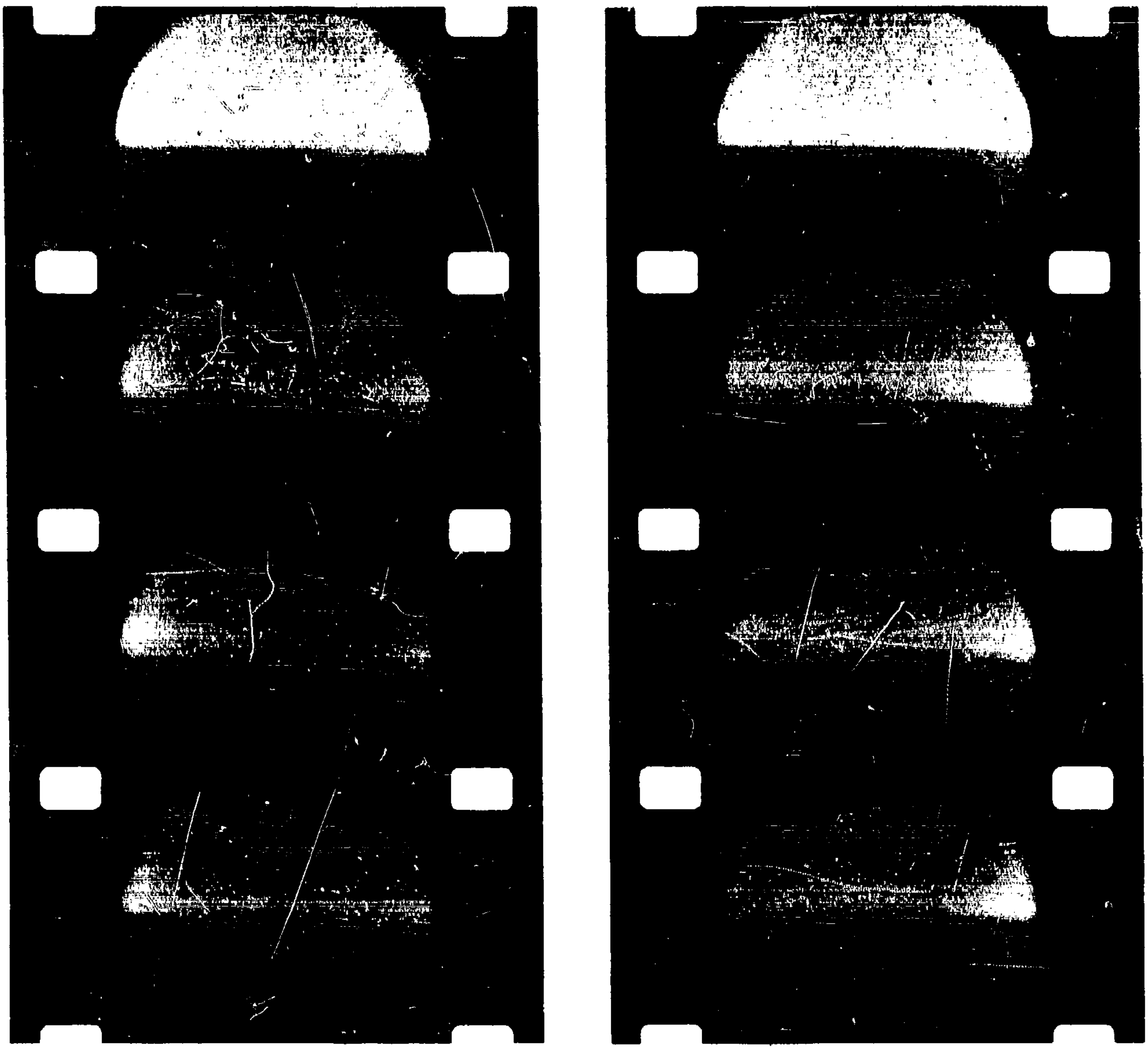


Four frames made at 1-second intervals from an altitude of 6000 ft. above a point approximately 3 miles SSE of Chatham, Mass., with the 146° lens system. The visibility is about 40 miles. Most of Cape Cod and Cape Cod Bay is shown in each of these pictures. Original exposures on Kodachrome.



Four frames made at 1-second intervals from an altitude of 1000 ft. above West Falmouth, Mass., with the 146° lens system. About 3 miles of shoreline are included although the distance to the nearest part of the beach is under 3/4 of a mile. Original exposures on Kodachrome.

FIG.8



The vis!ble expression of the Gulf Stream front photographed at 72 frames per minute with the 65° lens system from an altitude of 1000 ft., approximately 40 miles East of Cape Hatteras on 23 October 1952. The left hand strip shows what is presumed to be Gulf Stream water in the foreground' and Slope water in the background. The right hand strip shows what is presumed to be Gulf Stream water on the extreme right and Slope water on the extreme left, with a band of intermediate colored water in between. There is a pronounced wave in the left hand margin of the intermediate color band. The characteristic change of sea state was most marked along the boundary on the extreme right.

FIG.9

photography. These are designed to follow the gnomonic rules of perspective and cover fields in the order of only one radian. Nevertheless, this is nearly twice the greatest width of field formerly available in ordinary stock objectives, and this type of construction permits them to work at high relative aperture.

In addition to these refracting systems there are reflecting systems which are used for ultra-wide-angle astronomical work. At the Yerkes Observatory optical shop a system has been built which works at f/2 and provides critical definition over a field of 140°. The field compressor is a concave spherical reflector. The curvature of field present in this component is balanced by a modified Petzval-type camera objective which forms the final image on a flat plate.

It is found that a parabolic reflector in place of the spherical one in the Yerkes system will yield gnomonic perspective if the camera lens is placed about four focal lengths from the vertex of the paraboloid. This modification of the astronomical system may have uses in underwater photography. In photographing the bottom the camera would be pointed straight up into the reflecting field compressor, and presumably it would be possible to mount the light source directly below the camera so that the illuminating light paths would be as short as possible. Such a system could be made to operate at very high relative aperture and the light requirements reduced correspondingly. The depth of field in any system utilizing field compressors is very large so that focusing would be less of a problem than at present. The reflecting system has the advantage that the law of reflection applies without reference to the refractive index of the matrix medium. Presumably suitable reflectors would be constructed of corrosion-resistant alloys to survive immersion in sea water and rough usage. A compass might be centrally mounted in the focal surface of the field compressor where otherwise the camera image would appear, and a vent cut through the reflector behind the compass to release trapped air.

The extreme depth of field possessed by these systems is useful and is a consequence of the fact that the field compressor has a short focal length and does not form its image on a sensitized surface. The small conjugate motions of the primary image are reduced still more at the plane of the final image. When a collimator is mounted immediately ahead of the final image-forming component the focus of the entire system can be altered by focusing the collimator alone. This permits the system to be used conveniently at ranges in the order of the focal length of the field compressor without requiring allowance for changes in the calibration of the iris diaphragm in the camera lens. Some experiments utilizing this principle have been made on photography of small objects such as the smaller flowers, the structure of compound flowers, insects, and so on. Exposure offered no problem and the combination of intimate perspective with orthographic projection seemed to have unusual pictorial possibilities which are not available with conventional double or triple extension techniques.

Conclusion

Little of the material of this report is original and yet it is difficult to find very much discussion of these particular properties of optical trains either in texts or in journals devoted to optical subjects. A list of sources referred to during this work may be helpful to others who find its possibilities of interest.

Books

The Principles of Optics (Hardy and Perrin) McGraw-Hill, N. Y., 1951.

The Mannual of Photogrammetry (Am. Soc. Photogrammetry) Wash., D. C., 1951.

Elements of Map Projection (Deetz and Adams) U.S.C. and G.S. Spec. Pub. 68, 1945.

Topographic Trigonometric and Geodetic Surveying (Wilson) Wiley, N. Y., 1952.

Lenses in Photography (Kingslake) Garden City Books, N. Y., 1951.

Fundamentals of Optical Engineering (Jacobs) McGraw-Hill, N. Y., 1943.

Eastman Motion Picture Films for Professional Use. Eastman Kodak Co., Rochester, N. Y., 1951.

Papers

Miscellaneous Optical Designs (Section 16.1 NDRC) Yerkes Optical Bureau, 1945.

Richard, 1889 German Patent 117015

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